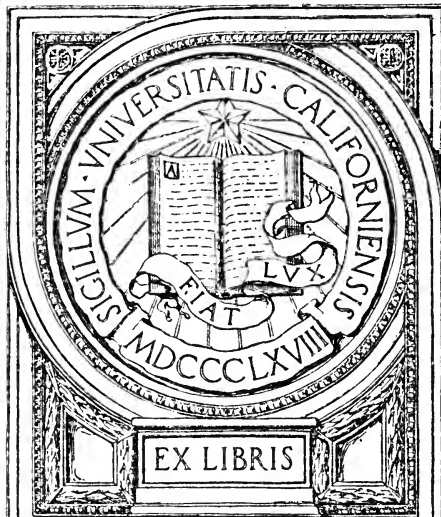


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BULLETIN OF THE UNIVERSITY OF WISCONSIN

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FROSTS IN WISCONSIN: OCCURRENCE, PREDICTION,  
AND METHODS OF PREVENTION

BY

JAMES L. BARTLETT

*Assistant Professor of Meteorology  
University of Wisconsin*



MADISON, WISCONSIN

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## FROSTS IN WISCONSIN: OCCURRENCE, PREDICTION, METHODS OF PREVENTION

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### FROST FORMATION

What is frost? The ordinary idea of frost is associated with the appearance, early some mornings of the cooler months, of a white deposit of frozen moisture upon vegetation and other objects near the ground. This is also sometimes termed white or hoar frost, to distinguish it from "black" frost which is an occurrence of freezing temperature without any deposit of moisture. The object upon which frozen moisture is deposited must have a temperature of  $32^{\circ}$ <sup>1</sup> or lower, though the air temperature a little distance away may be above freezing; so the observation of white frost is of value as indicating the occurrence of a freezing temperature at the surface of the ground. From an economic point of view, however, the freezing temperature is more important than the deposit of frozen moisture. So frost may be considered to include all occurrences of such temperature, at or near the surface of the ground, during the season of the growth of vegetation.

By the United States weather bureau frosts are separated into three general classes: "light" frosts causing damage only to tender plants and vines: "heavy" frosts representing a copious deposit of frozen moisture, but not killing the staple products of the locality: "killing" frosts destructive to vegetation and staple products, and for convenience often taken as contemporaneous with a thermometric record of  $32^{\circ}$  or lower in a thermometer shelter some little distance above the ground.

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<sup>1</sup> All temperatures mentioned herein are in degrees F.

*Atmospheric moisture.* Dry air is unknown in nature. The atmosphere at all times contains a certain amount of moisture, either visible or invisible. At a temperature of  $56^{\circ}$  air may contain 5 grains of invisible water vapor per cubic foot: at  $36^{\circ}$  it can contain only half as much, due to the fact that its capacity for moisture diminishes rapidly with its decrease in temperature. So, if air is cooled, it will reach a temperature (known as its dew point temperature) below which it can no longer hold in an invisible form all of its moisture content, some of which will then become visible. This cooling process is continually occurring in the atmosphere, either rapidly and through large masses when the condensed moisture falls as rain or snow, or more slowly at the earth's surface when the moisture becomes visible to us as dew or white frost deposited upon low objects. As to whether the condensed moisture assumes the form of rain, or of snow—of dew, or of frost—depends on whether the temperature at which condensation occurs is above, or is below,  $32^{\circ}$ , the freezing point.

With a temperature below  $32^{\circ}$  air may still contain invisible moisture, and if it contains only 1.5 grains per cubic foot, it may be cooled to a dew point of  $25^{\circ}$  before any frozen moisture is deposited. Under such conditions "black" frost occurs.

*Heating and cooling of the atmosphere.* The warmth of the atmosphere is controlled by the sun. During the day, while the sun shines, the air temperature increases. At night the air cools. Both heating and cooling, however, are indirect. The sun's rays pass through the air, without warming the latter to any extent, to the ground which becomes heated. The air next the warm earth then becomes warmed by conduction and expanding, rises, carrying its heat upward into the mass of the atmosphere. Thus radiation, conduction and convection of heat are all necessary to the warming of the air. Similarly at night the air itself gives off little heat by radiation, but the earth's surface and vegetation and other objects upon it radiate heat rapidly and become much cooler than the overlying air, which then cools by conduction. So we find that the surface of the ground is the active agent for both heating and cooling, and is warmer by day and cooler by night than the air above it.

## CONDITIONS AFFECTING FROST OCCURRENCE

## ATMOSPHERIC

*Temperature.* It is, of course, essential that the temperature of the air at the point where frost occurs should fall to the freezing point, though at a short distance above the ground the temperature may be as high as  $40^{\circ}$ . Also the warmer the air is during the day, the less liable is frost to occur on the following night. For example, an afternoon on which the temperature does not rise above  $60^{\circ}$  and begins to fall rapidly toward sunset is much more liable to be followed by a frosty night, than a hotter afternoon or one which cools slowly at sunset. During the past three years the maximum range of temperature in any one day (difference between highest and lowest) at Madison for the growing months has been as follows:

May,  $42^{\circ}$

June,  $29^{\circ}$

July,  $29^{\circ}$

Aug.,  $29^{\circ}$

Sept.,  $29^{\circ}$

The above figures indicate that, except possibly in May, a maximum afternoon temperature of  $65^{\circ}$  is not liable to immediately precede a night killing frost at Madison.

Another relation of temperature is in connection with late spring frosts. An unusually warm spell occurring early in the spring will often cause buds to start so that killing frosts later will cause much damage. If, on the other hand, cool weather prevails until late in the spring, the beginning of plant growth will be retarded so that late frosts will not be especially destructive. Water surfaces are known generally to retard the normal increase of air temperature in their vicinity in the spring, and this is considered one of the important ways in which they prevent damage by frost at that season.

*Winds.* Some wind directions are notably colder than others. Frosts as a rule occur with the colder, northerly to westerly winds rather than with the warmer southerly ones. Much wind from any direction is unfavorable for frosts, as it mixes the cold air next the ground with the warmer air above and thus tends to prevent inversions of temperature. As before mentioned, winds coming over a water surface are unfavorable for frost. The wind conditions which most favor the occurrence of frost are calms or gentle west to northwest winds near an anti-cyclonic, or high barometric pressure center.

*Moisture.* The presence of water vapor in the air is considered to have much to do with the occurrence of frost. The condensation of this water vapor sets free a considerable amount of latent heat which retards further cooling of air. A dew point above  $32^{\circ}$ , necessitating the condensation of moisture before the air temperature can fall to the freezing point, therefore is unfavorable for the occurrence of frost. Water vapor is also known to have great power for absorbing the heat rays given off by the earth. So the presence of water vapor in considerable amounts near the ground would tend to retard the cooling of the lowest layer of air.

*Clouds.* These consist of minute particles of condensed moisture suspended in the air. They, too, have marked influence in preventing the escape of heat from the earth as they reflect back heat radiated from that body. Frosts do not, as a rule, occur on cloudy nights, and the clouding up of the sky during the night will sometimes prevent the occurrence of an expected frost.

#### LOCAL CONDITIONS AFFECTING FROST

When atmospheric conditions are favorable for the occurrence of light frost, it is frequently noted that such frosts will occur and cause damage in one spot, while perhaps in an adjacent field no signs of frost can be detected. An investigation of this variation in place of occurrence, and of the reasons therefor, has shown that in any locality there are certain local influences favoring, or tending to prevent, the occurrence of frost. These



influences may be stated briefly as:—the elevation and slope of land; the character, condition and covering of the soil; and the proximity of water surfaces.

*Elevation.* The cooling of the lower atmosphere at night tends to produce abnormal temperature conditions near the ground. Normally the air temperature decreases as we go upward and at high elevations low temperatures are recorded. This cold, upper air does not sink toward the earth on account of its lack of density. At night, however, as heat is radiated from the earth's surface, we find that the air next the ground cools rapidly by conduction and becomes colder, and therefore heavier, than that at a little distance above it. On a plain this night-cooled air, being heavy, remains at the surface of the ground, continuing to give up its heat, by conduction and radiation, until it is much cooler than the air a short distance above it. In a rolling country the cold air on a hill top, being heavier than the surrounding air at the same elevation, tends to flow down into the adjacent hollows and valleys. Warmer air moves in upon the hill top or slope, to replace that which has descended, and near the end of a night when considerable cooling of the earth's surface has occurred much difference in air temperature may be found between the top or side of a hill and the bottom of a neighboring valley.

*Inversions of temperature.* Such abnormal distributions of heat in the air are known as inversions of temperature. While they occur most markedly in mountain regions and during the clear, quiet, long nights of winter, they are of common occurrence at all seasons and in all localities. Therefore, when atmospheric conditions are favorable for the temperature to fall barely to the freezing point, as sometimes happens in Wisconsin during late spring, summer, or early fall, frosts are quite likely to occur on lowlands and on level plains when hillsides nearby are untouched. Killing frosts have occurred in the cranberry marshes of northern Wisconsin when the lowest temperature recorded at nearby weather bureau stations was  $10^{\circ}$  or  $12^{\circ}$  above freezing. Comparative observations, taken by the Wisconsin Agricultural Experiment Station, of minimum night temperatures at heights of two inches and of three feet above a

cranberry marsh show that the lower point averaged over seven degrees cooler during an entire growing season. As the marshes are quite level and of considerable extent these temperature differences are due simply to the rapid night cooling of the air close to the ground, no vertical currents occurring.

Experience in other regions leaves no doubt that slopes and crests of hills are much freer from frost than valleys, lowlands, or level plains. In North Carolina and California, regions known as "Thermal Belts" are found, located upon the sides of mountains, high enough above the valleys to be free from early fall frosts, but not extending into the cold upper air. One of these belts in Polk county, N. C., is said to extend from 1,200 feet above sea-level to an elevation of 2,200 feet, being most perfect at 1,500 feet; to have a length of 8 miles, and to be distinguished by a magnificent flora such as would be characteristic of a point 3 degrees further south in latitude. In portions of Brazil coffee plantations are confined to the hills, to escape damage by frosts which occur in the lowlands. In the Swiss Alps dwellings are often placed high up from the fertile valleys, to avoid the intense winter cold of the latter. In England, in May, 1894, killing frost occurred in valleys, while ash trees on surrounding hills were untouched.

*Slope.* As the occurrence of frost depends upon the cooling of the earth's surface to the freezing point, the temperature of the surface layer of soil is of some importance. Frost is less liable to occur upon a soil which has been well warmed by the sun's rays, than upon a cold soil. The soil on southern slopes is well known to be warmer than that of northern, and, other things being equal, the former should be less liable to frost. Also, the cold, descending currents of air may follow depressions which thus become more liable to damage, although in general, as has been mentioned, any considerable air movement tends to prevent frost.

*Water surfaces.* The presence of any considerable body of water has much influence in preventing the occurrence of frost in its vicinity. This is due to the fact that water gives up its heat during the night much more slowly than the land, and rarely, during the growing season for vegetation, does a water

surface cool to the freezing point. Also the moisture of the atmosphere comes largely by evaporation from water surfaces and is more abundant in their vicinity; this will be shown later to be influential in preventing frost. Especially to the leeward of bodies of water is this influence marked. The cold air which crosses such water surfaces becomes both warmed and moisture laden, so that the falling of its temperature to the freezing point is retarded. Notable examples of regions thus favored with whole or partial immunity from frost, are the Pacific coast and the eastern and southern shores of the great lakes. Not only do large bodies of water have this frost-preventive influence, but also small lakes and rivers are known to hinder the occurrence of low night temperatures in their vicinity. On the east side of the Indian River, in Florida, frost is said to be unknown.

*Character and covering of soil.* Different soils differ considerably in their ability to absorb and radiate heat. Well drained soils become warmer than those which are saturated with water. A wet soil, too, besides not warming readily, cools still further during the night by the evaporation of water from its surface. Dense vegetation also tends to prevent warming of the soil, and to cool it by evaporation from its leaves. Experiments on the Wisconsin cranberry marshes indicate that a well drained soil, free from weeds and unnecessary vegetation, is less liable to frost than damp, weedy, unpruned plots. A surface which is flooded with water, however, partakes of the nature of a free water surface, and so may become less subject to frosts, especially if the water used in flooding is comparatively warm.

## SUMMARY

	CONDITIONS.	
	Favoring frost.	Preventing frost.
<i>Atmospheric.</i>		
Temperature.....	Low .....	High.
Movement.....	Calm.....	Much wind.
Wind direction.....	N. to S. W.....	N. E. to S.
Humidity .....	Low .....	High.
Dew point.....	Low .....	High.
Pressure, barometric.....	Above normal.....	Low.
Sky .....	Clear.....	Cloudy.
<i>Local.</i>		
Elevation.....	Valleys .....	Hill tops.
Slope.....	Level or northerly.....	Southerly.
Water surfaces.....	Near and to W. or N....	Far or to E.
Soil .....	Warm, dry.....	Cold, wet.
Soil covering.....	Dense.....	Light.

## FROSTS AT MADISON

The conditions under which frosts have occurred at Madison are shown in the right hand side of Table I. Clear skies and light winds from a westerly direction, with a sea level barometer reading of 30.10 inches or over have usually attended the frosts. The minimum temperature recorded in the instrument shelter has usually been below 40°.

TABLE I. LOCAL WEATHER CONDITIONS PRECEDING AND ATTENDING THE OCCURRENCE OF FROSTS AT MADISON, WIS.

CONDITIONS AT 12 NOON ON DAY PRECEDING FROST.										CONDITIONS AT 7 A. M. ATTENDING FROST.					
Date.	Barometer reduced to sea level.	Barometer movement.	Temperature.	Approximate dew point.	Wind.		Sky.	Rainfall last 24 hours.	Date.	Character of Frost.	Barometer reduced to sea level.	Lowest temperature.	Wind.		Sky.
					Direction.	Velocity.							Direction.	Velocity.	
1904 October..	5	30.00	Falling.....	52	43	N W	Cloudy.....	Trace	9	Light...	30.53	39	N E	6	Clear.
	22	29.89	Rising.....	40	32	N W	Cloudy.....	0.04...	23	Heavy	30.14	34	W	8	Clear.
	25	30.30	Stationary..	40	29	N W	Clear.....	None.	26	Heavy	30.11	33	S W	5	Clear.
	26	30.18	Rising.....	43	30	N W	Clear.....	Trace	12	Killing.	30.41	34	E	2	Clear.
	11	29.92	Stationary..	39	30	N W	Cloudy.....	Trace	17	Killing.	30.02	34	W	8	Cloudy.
1905 October..	15	29.75	Rising.....	46	44	N W	Cloudy.....	Trace	16	Light...	30.25	36	W	7	Clear.
	20	30.16	Rising.....	38	29	N W	Cloudy.....	0.37...	21	Killing.	30.27	33	W	14	Cloudy.
	27	30.20	Rising.....	39	26	N W	Partly cloudy..	Trace	28	Killing.	30.59	26	N W	17	Clear.
	8	30.04	Rising.....	38	34	N W	Cloudy.....	0.40...	9	Light...	30.33	33	W	13	Clear.
	30	30.37	Falling....	57	40	N E	Clear.....	None.	1	Light...	30.16	43	0	0	Clear.
1906 May.....	9	30.05	Rising.....	38	26	N W	Cloudy.....	Trace	10	Killing.	30.18	26	N W	19	Clear.
	30	30.16	Rising.....	40	27	N W	Clear.....	0.03...	1	Killing.	30.30	32	S	5	Clear.
	3	30.25	Stationary..	35	29	N E	Cloudy.....	Trace	4	Killing.	30.29	32	N E	2	Clear.
	5	30.02	Falling....	44	38	N	Cloudy.....	Trace	6	Heavy	30.07	32	N E	4	Clear.
	8	29.96	Falling....	39	36	N	Cloudy.....	Trace	9	Heavy	29.97	32	S E	9	Clear.
1907 Sept.....	10	30.10	Stationary..	33	27	N	Cloudy.....	0.03...	11	Killing.	30.21	30	N E	4	Clear.
	21	29.85	Stationary..	67	40	N W	Clear.....	None.	22	Light...	30.09	37	S W	6	Clear.
	24	29.77	Rising.....	49	38	N W	Partly cloudy..	None.	25	Light...	30.26	36	N W	9	Clear.
	7	29.62	Rising.....	55	40	N W	Cloudy.....	Trace	8	Heavy	30.22	36	N	3	Clear.
	12	30.32	Rising.....	41	30	N W	Partly cloudy..	0.06...	13	Killing.	30.42	29	N W	6	Clear.
1908 May.....	1	29.65	Falling....	51	34	N W	Partly cloudy..	0.02...	2	Killing.	29.79	31	N W	24	Pa'ly cloudy
	1	29.65	Rising.....	43	28	N W	Partly cloudy..	0.09...	3	Light...	29.99	35	N W	3	Clear.
	2	29.86	Rising.....	43	28	N W	Partly cloudy..	0.09...							

## OCCURRENCE OF FROST IN WISCONSIN

## THE KILLING VARIETY

*Sources of data.* For a number of years past numerous co-operative stations of the weather bureau have been maintained throughout Wisconsin, besides several regular observing stations located in the larger cities. At all of these stations the highest and lowest daily temperatures are obtained by using maximum and minimum thermometers, which are mounted in a shelter with lowered sides and double top. The object of the shelter is to protect the thermometers from the direct rays of the sun and from the rain, either of which influences would prevent obtaining the true air temperature. For most of the co-operative stations the height of the thermometers above ground is not over 5 feet, but at the large city stations it has been found desirable to place the thermometer shelters on the roofs of buildings often 100 or more feet above the ground.

When it has not been possible to observe otherwise the annual limits of killing frosts, the dates of these have been taken from the last and first occurrences, respectively, of freezing temperatures in spring and autumn, as recorded by the minimum thermometers. This should be borne in mind in considering the data, for during the frost-favoring inversions of temperature naturally the thermometers in a shelter some distance above the earth will not record as low a degree of temperature as occurs upon the ground.

The accompanying charts, Plates I and II, show the average dates of occurrence of last killing frost in spring and of the first in autumn over Wisconsin. These charts are, in general, based upon the data contained in Table 2, but minor local influences have been neglected in preparing the charts.

Plate I shows that as a rule killing frosts occur until June 1 in some of the northern interior counties, but not after May 10 in the Mississippi bottoms, the southern tier of counties and

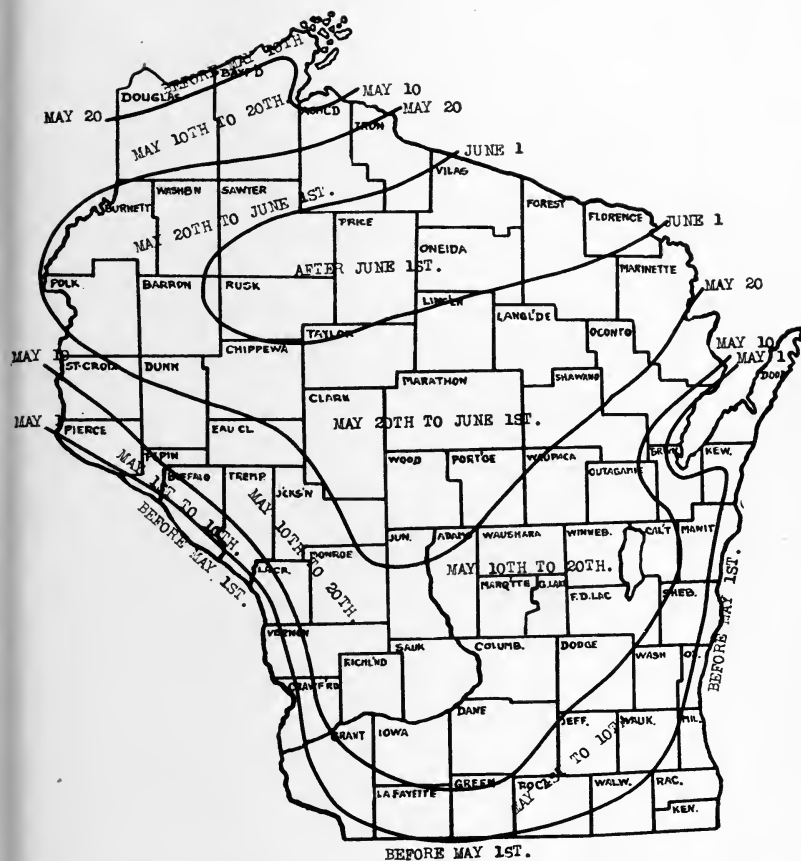


PLATE I.—AVERAGE DATES OF LAST KILLING FROST IN SPRING.

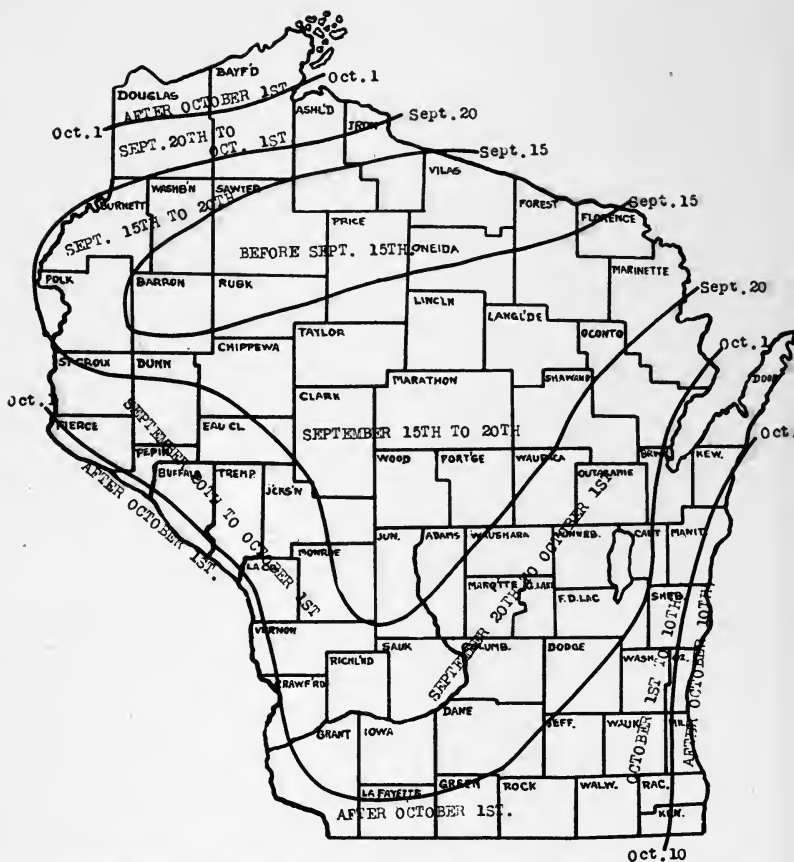


PLATE II.—AVERAGE DATES OF FIRST KILLING FROSTS IN AUTUMN.



those along the Lake Michigan shore, and over the Lake Superior shore.

Plate II shows that the average date of first killing frost in the fall is Sept. 15 in the northern interior, but that such frosts do not occur until October 1st, or later, along the shores of the great lakes and Mississippi river and in the extreme southeastern counties.

These charts show very clearly the influence of the great lakes upon the occurrence of frosts. Going westward across the middle of the state from Lake Michigan we find that in the interior killing frosts occur 20 days later in spring and the same amount earlier in autumn than on the lake shore. The portion of the state least free from frosts, instead of being in the extreme north, is forced by the influence of Lake Superior southward into the interior. The Mississippi river also appears to have some influence upon frost occurrence.

Table II gives for a number of places over or adjacent to the state, the average and extreme limits of killing frosts. These places have been grouped as much as possible according to their similarity of location.

*Averages for different sections.* The average frost limits and length of growing season for the different sections of the state are shown in the following table, in the order of their degree of frost immunity:

TABLE II. AVERAGE AND EXTREME LIMITS OF KILLING FROSTS IN WISCONSIN.

Region.	Place.	County.	AVERAGE DATES OF		EXTREME DATES OF	
			Latest Spring.	Earliest Autumn.	Latest Spring.	Earliest Autumn.
Lake Superior Shore.	Duluth, Minn.....	.....	May 2	Oct. 9	*June 8	*Sept. 15
	Marquette, Mich.....	.....	May 4	Oct. 12	*June 11	*Aug. 22
	*Washburn.....	Bayfield.....	May 16	Oct. 12	June 5	Sept. 25
Northern Interior.	*Barron.....	Barron.....	May 30	Sept. 14	June 29	Aug. 6
	Florence.....	Florence.....	June 2	Sept. 13	June 15	Aug. 19
	Grantsburg.....	Burnett.....	May 21	Sept. 19	June 11	Sept. 9
	Hayward.....	Sawyer.....	May 25	Sept. 14	*June 30	*Aug. 9
	*Koenigick.....	Langlade.....	May 29	Sept. 16	June 24	Aug. 12
	Medford.....	Taylor.....	May 28	Sept. 19	June 30	*July 29
Middle Interior.	Osceola.....	Polk.....	May 23	Sept. 17	June 12	*Aug. 27
	*Amherst.....	Portage.....	May 16	Sept. 18	May 28	Sept. 10
	*City Point.....	Jackson.....	May 11	Sept. 16	June 14	Aug. 8
	*Chilton.....	Calumet.....	May 15	Oct. 4	June 12	Sept. 20
	Eau Claire.....	Eau Claire.....	May 12	Sept. 26	June 12	Sept. 11
	Fond du Lac.....	Fond du Lac.....	May 17	Sept. 25	June 12	Sept. 12
	*Hancock.....	Waushara.....	May 16	Sept. 24	June 12	Sept. 12
	Hillsboro.....	Vernon.....	May 18	Sept. 20	June 12	Sept. 11
	Meadow Valley.....	Juneau.....	May 21	Sept. 18	June 12	Aug. 8
	Neillsville.....	Clark.....	May 20	Sept. 20	June 12	*Aug. 29
	*New London.....	Outagamie.....	May 16	Oct. 1	June 12	Sept. 14
	*Oshkosh.....	Winnebago.....	May 5	Sept. 29	May 31	Sept. 9
	Pine River.....	Waushara.....	May 13	Sept. 26	June 12	Sept. 12
	Stevens Point.....	Portage.....	May 23	Sept. 24	June 30	Sept. 9
	*Valley Junction.....	Monroe.....	May 22	Sept. 20	June 30	Aug. 3
	Viroqua.....	Vernon.....	May 14	Sept. 28	June 12	*Sept. 12
	*Waupaca.....	Waupaca.....	May 16	Sept. 29	June 12	Sept. 19
Southern Interior.	Wausau.....	Marathon.....	May 24	Sept. 25	June 12	Sept. 11
	*Whitehall.....	Trempealeau.....	May 18	Sept. 25	June 12	Aug. 21
	*Beloit.....	Rock.....	Apr. 24	Oct. 8	May 20	Sept. 20
	*Brodhead.....	Green.....	May 1	Oct. 6	May 20	Sept. 18
	*Harvey.....	Jefferson.....	May 9	Oct. 3	June 12	Sept. 20
	Lancaster.....	Grant.....	May 4	Oct. 1	*June 12	Sept. 12
Mississippi River Bottoms.	Madison.....	Dane.....	Apr. 21	Oct. 18	*May 15	Sept. 30
	Portage.....	Columbia.....	May 6	Sept. 29	May 28	Sept. 11
	Watertown.....	Jefferson.....	May 9	Oct. 2	May 31	Sept. 19
	*Waukesha.....	Waukesha.....	May 3	Oct. 14	May 31	Sept. 24
	*Dubuque, Iowa.....	.....	Apr. 20	Oct. 12	May 21	Sept. 27
Lake Michigan and Green Bay Shore.	La Crosse.....	LaCrosse.....	Apr. 12	Oct. 8	*June 23	*Sept. 13
	Prairie du Chien.....	Crawford.....	Apr. 29	Oct. 1	June 1	Sept. 12
	St. Paul, Minn.....	.....	Apr. 28	Oct. 5	May 27	Sept. 20
	*Green Bay.....	Brown.....	Apr. 30	Oct. 10	*May 30	*Sept. 16
	Manitowoc.....	Manitowoc.....	Apr. 28	Oct. 16	*May 31	*Sept. 24
	Milwaukee.....	Milwaukee.....	Apr. 20	Oct. 15	May 29	Sept. 25
	Oconto.....	Oconto.....	May 15	Sept. 30	June 12	Sept. 10
	Port Washington.....	Ozaukee.....	May 10	Sept. 30	May 31	Sept. 10
	Racine.....	Racine.....	Apr. 26	Oct. 11	May 31	Sept. 18
	*Sheboygan.....	Sheboygan.....	Apr. 26	Oct. 12	May 11	Sept. 28

\*Data for other than 12 year period (1896-1907).

TABLE III.

SECTION.	AVERAGE DATES OF K. FROST.		Average length of growing season.
	Last spring.	First autumn.	
Mississippi River Bottoms.....	April 22..	Oct. 7..	168 days
Lake Michigan and Green Bay Shore .....	April 28..	Oct. 11..	166 "
Lake Superior Shore.....	May 7..	Oct. 11..	157 "
Southern Interior.....	May 6..	Oct. 6..	153 "
Middle Interior .....	May 16..	Sept. 24..	131 "
Northern Interior.....	May 27..	Sept. 16..	112 "

In the first three of the above sections it seems probable that the actual length of growing season is less than calculated, on account of the height of the thermometers above ground. The data in Table II show that Prairie du Chien, the only station in the Mississippi river bottom having thermometers exposed near the ground, has a growing season of 155 days, 13 less than the average for the section. Similarly at Port Washington the growing season is 23 days shorter than the average for the Lake Michigan shore, and at Washburn, 10 days shorter than the average for Lake Superior shore.

The data for the extreme frost limits at the various stations are also of interest, showing that spring frosts have occurred late in June over nearly the entire state, and that autumn frosts have occurred similarly early in September. Frosts in August are not rare at some of the interior stations, particularly in the cranberry growing section, and there is record of killing frost at Medford on July 29.

It is possible that the high elevation of the northern interior portion of the state is partially responsible for its liability to frost. Many points in that section have an elevation of 1,000 to 1,500 feet above sea level, and of 500 to 1,000 feet above the great lakes, making them somewhat more liable to low temperatures at night than are places of less elevation.

*Influence of small lakes.* An examination of the limiting dates of frost at points around Lake Winnebago gives an idea of the influence of that lake upon frost occurrence. Oshkosh is on the west shore of the lake and between it and, a little to the

southeast of, Big Buttes des Morts lake. Fond du Lac is at the southern extremity of Lake Winnebago. Chilton is about 7 miles east of the lake. The length of growing season at these different places is

Chilton	142
Fond du Lac	131
Oshkosh	147
Watertown	146
Harvey	147.

Harvey and Watertown are away from small lake influence and further south than the Lake Winnebago points; yet the former has no longer a growing season than Oshkosh and but little longer than Chilton. Undoubtedly the topography of the shores of a small lake has much to do with frost immunity influences. Oshkosh is on low ground, on the windward side of Lake Winnebago, but probably somewhat under the influence of Big Buttes des Morts lake. At Fond du Lac, which is on high ground at the extreme southern tip of the lake, the influence of the latter on frost occurrence is not great. The eastern shore of Lake Winnebago is quite steep, and Chilton is on the slope away from this lake and toward Lake Michigan; this doubtless explains why the growing season at Chilton is not even longer.

Similarly it is found that at Madison, which is between two small lakes, Mendota and Monona, the growing season is a month longer than at Harvey, which is directly east of the former, nearer Lake Michigan, but away from any small lakes. Like immunity from frost can doubtless be found around many of the small bodies of water in the northeastern portion of the state.

It is, of course, impossible to state exactly to what distance from these lakes their moderating influence upon the air temperature extends. With regard to the similar influence of the small lakes in the central part of the state of New York, Professor L. H. Bailey, in *The Principles of Fruit Growing*, makes the following interesting statement:

“The distance to which the ameliorating influence of the water may extend is determined very largely by the conforma-

tion of the shore lands. As a rule there are distinct slopes toward the water and it is rare that the effect of the water upon the temperature extends beyond the crest of the adjoining elevation. As a matter of fact, when the elevation is 300 feet, or more, the region of immunity from frost does not extend more than two-thirds of the distance to the summit. . . . The particular influence which the water exerts over injury by frost in the spring is often more due to the retardation of the period of bloom than to the actual prevention of frost, although its influence in the latter direction is important."

### LIGHT FROSTS

The occurrence of frosts lighter than "killing" is of some interest, but unfortunately the data for the limits of such frosts in Wisconsin are not abundant. It may be safely assumed, however, that light frosts on the average may occur at any point two or three weeks after the last killing frosts in spring, and the same length of time before the first killing frost in autumn. In this connection Table IV, showing comparative data for limits of light and of killing frosts at Madison, is of interest. When light frosts are not observed, they are presumed to occur when the minimum temperature falls to 40° with light winds and clear skies. On account of the control of frost limits at Madison by the lakes there, it is probable that the average differences between light and killing frost limits obtained for that point are not so great as at some other points. In fact there are undoubtedly places in the northern interior where light frosts have occurred during all the summer months.

TABLE IV. COMPARISON OF ANNUAL LIMITS OF LIGHT AND OF KILLING FROSTS.

	SPRING.		AUTUMN.	
	Last killing.	Last light.	First light.	First killing.
1904.....			Oct. 6.....	Oct. 27.
1905.....	April 21.....	April 30.....	Oct. 12.....	Oct. 21.
1906.....	April 23.....	May 23.....	Oct. 1.....	Oct. 10.
1907.....	May 11.....	May 23.....	Sept. 22.....	Oct. 13.
1908.....	May 2.....	May 3.....		
Average.....	April 29.....	May 15.....	Oct. 3.....	Oct. 18.
Average difference.	16 days.		15 days.	

## OBSERVATION OF FROST

The surest method of observing the occurrence of freezing temperatures is by the use of the minimum thermometer. One of these thermometers is shown in Plate III. It is an alcohol thermometer, having a small metallic index within the alcohol column. This index is drawn toward the bulb by the end of the column as the air cools and is left at the point of lowest temperature reached, the alcohol flowing by as the temperature rises again. This thermometer should be laid at night horizontally on the grass or vegetation where frost is expected, and in the morning the end of the index away from the bulb will mark the minimum temperature reached. Before exposing again the thermometer should be held bulb upward until the index drops to the end of the alcohol column: Care should be taken that the alcohol column is continuous and not separated by air bubbles, it being possible to remove the latter by jarring the instrument carefully. Minimum thermometers may be procured from many of the dealers in high grade thermometers.

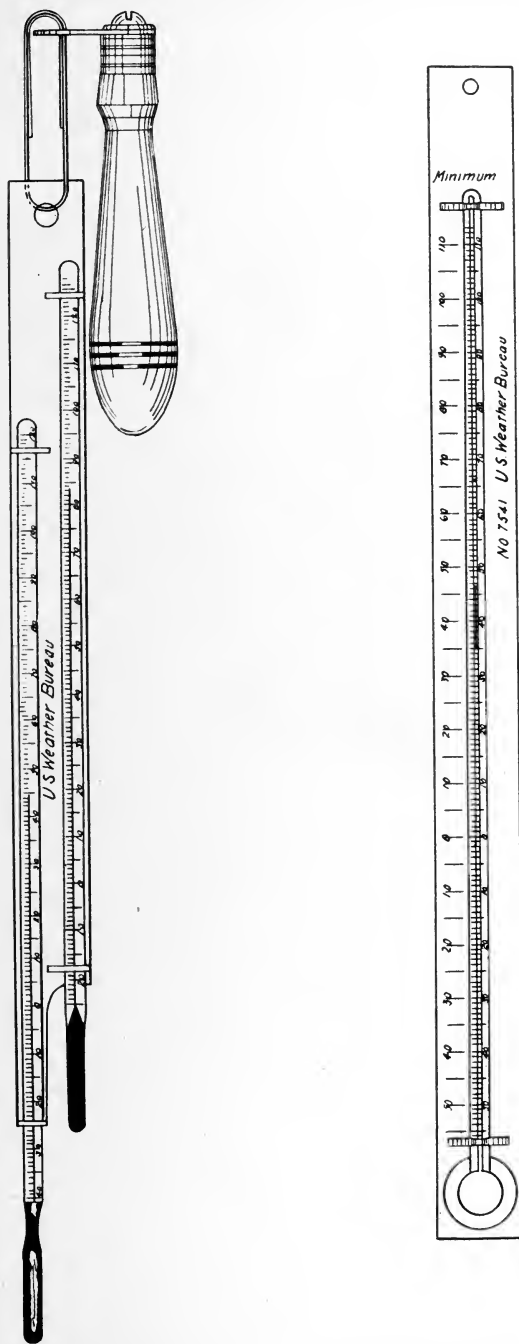


PLATE III.—SLING PSYCHROMETER AND MINIMUM THERMOMETERS.

## THE PREDICTION OF FROST

## LOCAL SIGNS OF FROST

The following extracts from *Weather Bureau Bulletin*, No. 294, *Weather Folk-Lore and Local Weather Signs*, describe what are considered the local indications of frost at several places in, or near the borders of Wisconsin:

Milwaukee: Barometer rising above the normal, temperature falling to  $40^{\circ}$  or below, light westerly winds, and a clear sky.

Green Bay: Heavy frost is usually preceded by high barometer, moderately low humidity, northerly winds, and clear weather.

La Crosse: . . . rising barometer, temperature  $48^{\circ}$  or below, with indications of falling to  $36^{\circ}$  or below, light north to northwest winds, and often light rain on the day preceding the occurrence of frost.

St. Paul, Minn.: Heavy frost is preceded by high barometric pressure, temperature  $40^{\circ}$ , or slightly below, relative humidity 45 to 60 per cent., light west to northwest winds and few if any clouds.

Duluth, Minn.: Heavy frost is usually preceded by increasing and low barometer, relative humidity low and increasing from about 50 to 95 per cent., decreasing southwest and north winds, temperature falling to  $38^{\circ}$  or below, and clearing or clear weather.

Dubuque, Iowa: Heavy frost is generally preceded by low and rising barometer, falling temperature, high and decreasing relative humidity, and clearing weather.

Escanaba, Mich.: In spring and autumn frost usually occurs with rising and high barometer, clearing weather, and low humidity.

*Local signs at Madison.* Table I shows the local weather conditions both preceding and attending the occurrence of light, heavy and killing frosts at Madison during the past four years.



The preceding conditions were taken at 12 noon of the day preceding the frost, while the attending conditions are taken at 7 A. M., which is but little after the time of minimum temperature.

An analysis of the conditions preceding frost shows at once that such conditions vary much. In general, however, a barometer height of 30.00 inches (sea level) or over, with a tendency to increase, preceded most of the frosts. The temperature was seldom over  $50^{\circ}$  and the dew point was usually below  $40^{\circ}$ . The wind direction varied much but in 64 per cent. of the cases was from a westerly point; the wind velocity was usually between 10 and 20 miles an hour. The sky was generally more or less obscured by clouds, and small amounts of rain had fallen. Those who are familiar with the weather maps will recognize the above conditions as being those which immediately follow the passage of a low pressure area across the meridian of a place and precede the approach of a "High."

From the Madison conditions the following general rule might be made: Frost may be expected when fresh westerly winds, with partly cloudy to cloudy weather following light rainfall, are accompanied by a rising barometer, reading 30 inches (reduced to sea level) or over, and by a temperature below  $50^{\circ}$  and dew point below  $40^{\circ}$ .

*Instruments needed for predicting frost.* For determining the above conditions certain instruments will be necessary, although it is possible to determine some of them by the eye alone. For instance, the wind, sky, and rainfall may be observed with sufficient accuracy without instruments. For height of barometer either a mercurial or aneroid instrument may be used, the latter being compared with one of the former occasionally. The ordinary barometer reading should be reduced to sea level by adding 1.1 inches per 1,000 feet of elevation. The temperature and the dew point may both be obtained by the use of the sling psychrometer, shown in Plate III. This instrument consists of **two thermometers**, exactly alike except that the bulb of one is covered with muslin which is to be moistened with water. The instrument is then whirled in the air, evaporation of the water on the muslin lowering the temperature of its bulb, until no further

lowering of temperature can be obtained. The thermometer with uncovered bulb shows the dry temperature desired. By using this dry temperature and the difference between the two thermometers in Table V the dew point may be obtained. For example, with the dry bulb thermometer reading  $52^{\circ}$  and the wet bulb reading  $43^{\circ}$  a difference of  $9^{\circ}$  will be obtained. Entering Table V in the column headed 9 and coming down opposite the temperature of 52 in the extreme left hand column, a dew point of  $32^{\circ}$  is found.

The use of the dew point in predicting frost is based upon the principle previously mentioned that when air has cooled to its dew point, further cooling will be retarded by the liberation of latent heat. Further cooling may occur, however, and in Wisconsin it has been found that air often cools at night many degrees below the dew point observed in the afternoon, such cooling being accompanied by copious deposits of dew or by frost.

In general a dew point of  $42^{\circ}$  or less during the afternoon, unless other conditions are very unfavorable to frost, is considered to favor its occurrence the following night.

TABLE V.—TEMPERATURE OF THE DEW POINT IN DEGREES F.

Air temperature.	Difference between dry and wet bulb thermometers.																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
40.....	38	35	33	31															
42.....	40	38	35	33	30														
44.....	42	40	38	35	32	30													
46.....	44	42	40	37	35	32	30												
48.....	46	44	42	40	37	35	32	30											
50.....	48	46	44	42	40	37	35	32	29										
52.....	50	48	46	44	42	40	37	35	32	29									
54.....	52	50	49	47	44	42	40	38	35	32	29								
56.....	54	53	51	49	47	45	43	40	38	35	32	29							
58.....	56	55	53	51	49	47	45	43	40	38	35	32	29						
60.....	58	57	55	53	51	49	47	45	43	41	38	35	32	29					
62.....	60	59	57	55	54	52	50	48	46	43	41	38	35	32	30				
64.....	62	61	59	58	56	54	52	50	48	46	44	41	38	36	33	30			
66.....	64	63	61	60	58	56	54	53	51	48	46	44	42	39	36	33	30		
68.....	67	65	63	62	60	58	57	55	53	51	49	47	44	42	39	36	33	30	
70.....	69	67	66	64	62	61	59	57	55	53	51	49	47	45	42	40	37	34	31

All below freezing.

## PREDICTION FROM WEATHER MAP

*Frost warnings.* During seasons when frosts may cause damage to crops warnings are telegraphed from the weather bureau office in Chicago by the district forecaster in charge to numerous centers throughout Wisconsin. From these centers the warnings are distributed chiefly by mail or telephone. Anyone who is connected with a telephone system should be able to obtain such warnings by noon of the day preceding any frost which is expected by the weather bureau. These warnings are based on a weather map which shows atmospheric conditions over the United States at 7 A. M. (90 meridian time), the data being collected by telegraph during the early forenoon hours. As the warnings are of a general character, covering large sections, and intended for the protection of the more important crops, they may not always apply to particular locations. Copies of the weather map upon which these warnings are based are issued, however, from the weather bureau offices at Milwaukee, Madison, La Crosse and Green Bay, Wisconsin, and Duluth and St. Paul, Minnesota, Dubuque, Ia., and Escanaba, Michigan, and mailed to numerous points in this state for public display. For the benefit of those to whom such maps are accessible, a slight explanation of them will be given so that they may be understood and used more advantageously.

*Information contained on maps.* The map itself, as previously stated, shows weather conditions at 7 A. M. central time. Iso-bars, or continuous lines, pass through points of equal air pressure reduced to sea level. Isotherms, or dotted lines, pass through points of equal temperature. Symbols indicate state of weather: ○ clear; ⊖ partly cloudy; ⊕ cloudy; R rain; S snow; M report missing; ⚡ thunderstorm. Arrows fly with the wind. Shaded areas show regions of precipitation during past 24 hours. Places for which no data are given may be considered to have conditions similar to, or averaging between those of surrounding points. The data in the table are self-explanatory. Weather forecasts and warnings and a general summary of weather conditions for the country are also given.

The words "High" and "Low" are placed on the maps at the various centers of highest and lowest barometric pressure respectively. These centers are known to move across the country in an easterly direction, though both their direction and rate of movement are often irregular. The "Highs" frequently move to the south of east and more slowly than the "Lows," which often move more to the northeast. The rate of movement averages 25 to 30 miles an hour though it may vary from 10 to 50. Upon this more or less regular movement, however, all weather forecasts, including those of frosts, are largely based. Therefore the study of the weather map conditions immediately preceding frosts becomes of much interest.

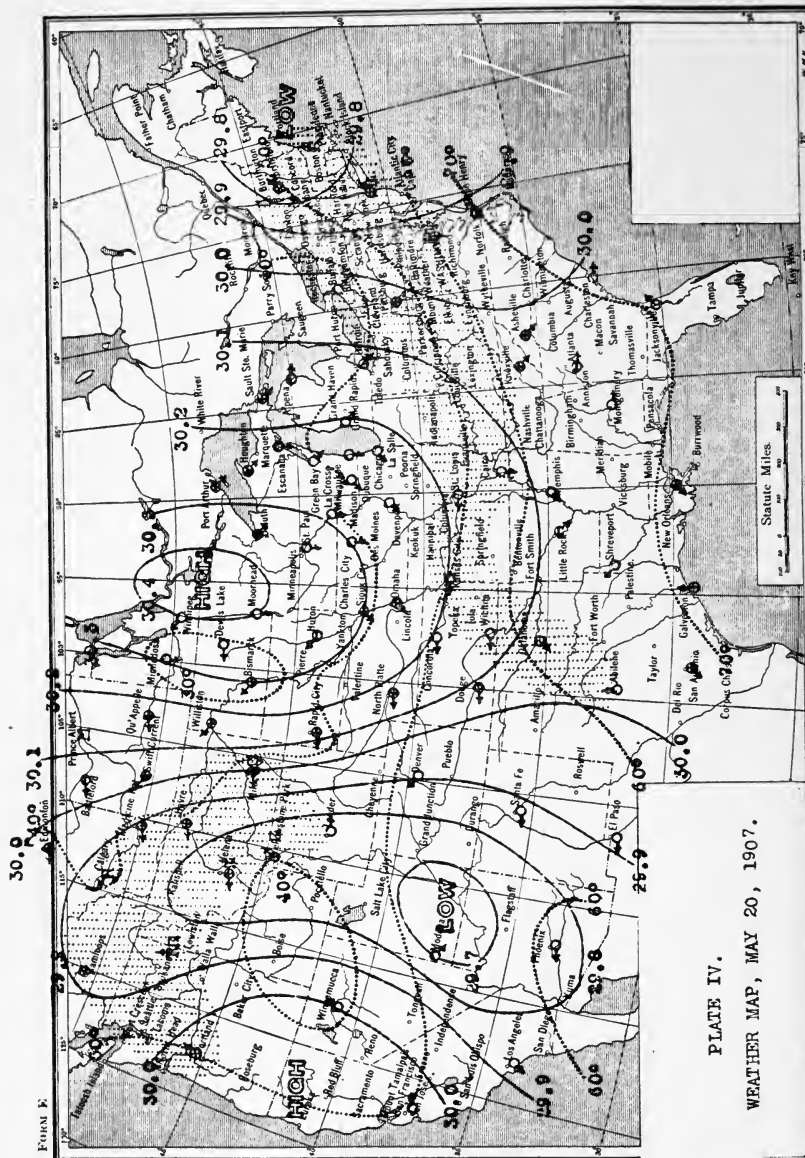
Table VI shows, in condensed form, the weather map conditions which have preceded some killing frosts in Wisconsin during the past five years. While these conditions vary it may be seen in general that a "Low" over the great lakes or adjacent region, and a "High" west or northwest of Wisconsin but east of the Rocky Mountains, with minimum temperatures in the Dakotas falling below  $40^{\circ}$  to  $50^{\circ}$ , are favorable for the occurrence of killing frosts in portions of Wisconsin the next night. The 7 A. M. temperatures have usually been below  $50^{\circ}$  to  $60^{\circ}$  (north to south over the state).

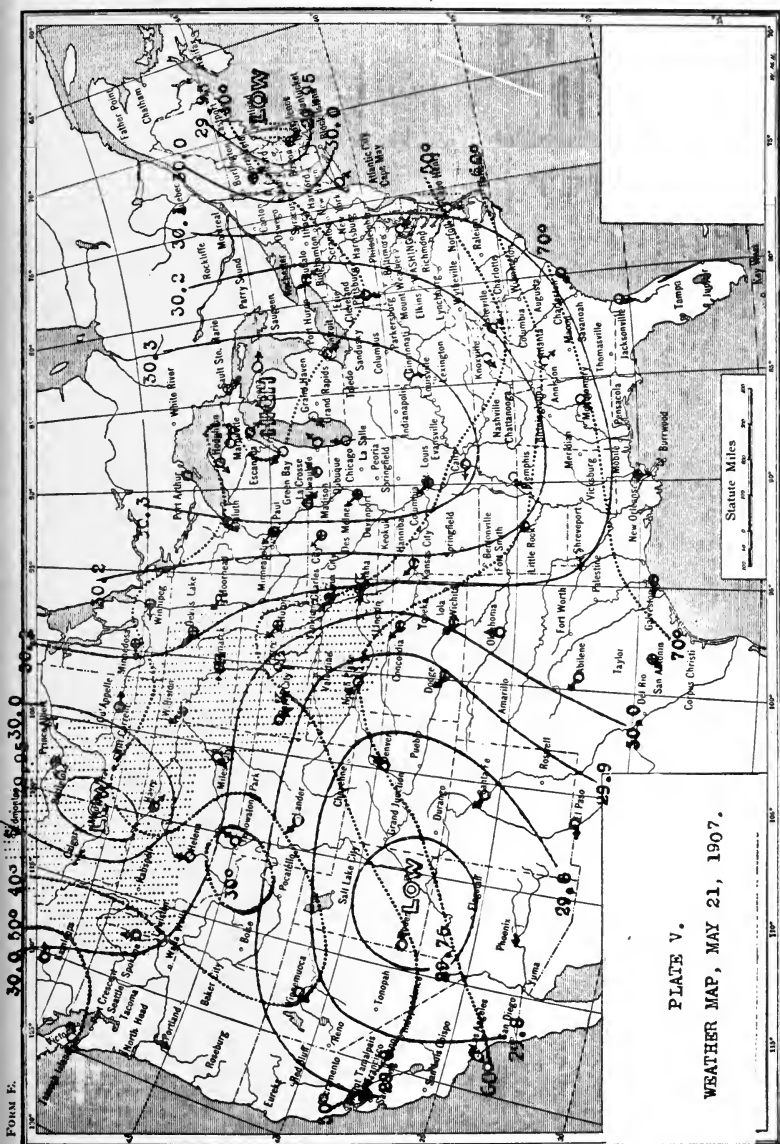
In cases where the frost has been killing over practically the entire state, the temperatures in the Dakotas have generally been below, and those in Wisconsin only a little above, freezing, on the day preceding. Light rainfall frequently preceded the frost, but, of course, has little to do with causing the latter, being rather an accompaniment of the "Low" as it passed across the state.

Plates IV to VII, inclusive, show the weather map conditions both preceding and attending two marked occurrences of frost in this state. On May 20, 1907, an area of high barometric pressure (High) was central over Minnesota, accompanied by clear, cool weather in that state; during the next 24 hours this moved to the great lakes, attended by frosts generally over Wisconsin. The conditions on October 7 to 8, 1907, were somewhat different as the "High" over southern Montana on the 7th moved southeastward, only a portion of its area extending over Wis-

TABLE VI. WEATHER MAP CONDITIONS OVER THE NORTHWEST PRECEDING SOME KILLING FROSTS IN WISCONSIN.

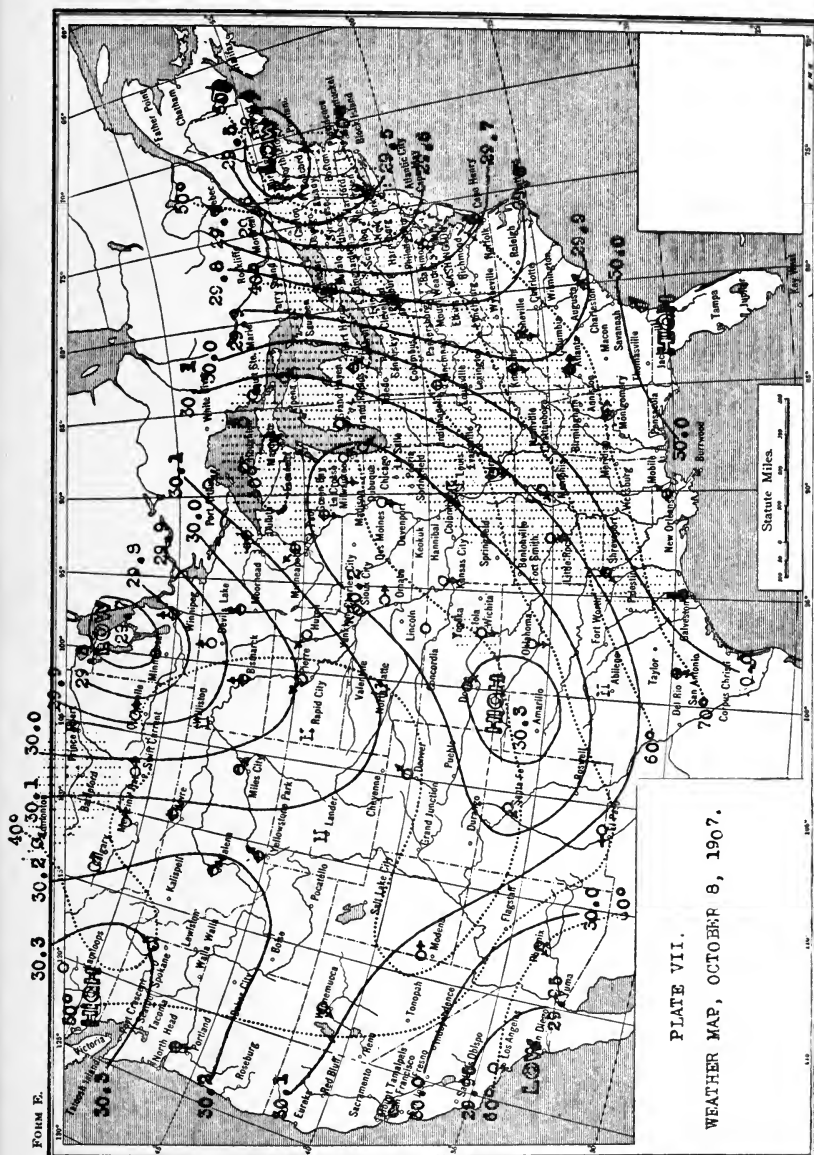
DATE.	HIGH PRES- SURE CENTER.		Value of Cen- tral Isobar.		LOW PRES- SURE CENTER.		Value of Cen- tral Isobar.		Minimum tem- peratures in Dakotas.		WISCONSIN.		FROST OCCURRENCE.	
	Location.				Location.						Precipitation during past 24 hours.	Tem- per- atures at 7 a. m.	Date.	Region affected.
1903 June..	10	N. Dakota....	30.5		Penn.....		30.0		30-42		Light.....	40-50	11	Much of northern and middle interior.
	11	S. Minn.....	30.4		N. Carolina....		29.0		34-44		Traces.....	40-50	12	Northern interior.
Sept....	4	Dakotas....	30.3		E. Canada.....		29.9		36-50		Local.....	45-60	5	
	16	Neb. Mont....	30.3		Lake Huron....		29.95		24-36		Local.....	40-50	17	
	23	Dakotas....	30.5		E. Canada.....		29.7		32-38		None.....	40-65	24	Northern interior and portions of middle in- terior.
	27	Nebraska....	30.1		E. Canada.....		29.8		30-38		Moderate...	35-45	28	
Oct....	4	Colorado....	30.2		Lake Sup'r....		29.7		34-42		Lt. to Mod...	40-50	5	
	15	W. L. Sup'r....	30.2		E. Canada.....		29.9		34-40		None.....	32-40	16	Much of interior.
May....	7	Dakotas....	30.2		Lake Mich....		29.9		40-44		Local.....	50-60	8	Portions of northern and middle interior.
Aug....	11	S. Dakota....	30.2		E. Canada.....		29.9		26-42		Lt. Local....	40-60	12	Northern and middle interior.
Sept....	20	N. Dakota....	30.6		E. Canada.....		29.9		22-38		Traces.....	40-60	21	Interior except extreme south.
	5	N. E. Mont....	30.6		Lake Huron....		29.9		30-38		Moderate...	35-45	6	General except Lake Michigan shore
Oct....	8	Manitoba....	30.3		Lake Huron....		29.8		26-36		Light.....	35-50	9	Portions of interior.
May....	25	Montana....	30.1		Lake Mich....		29.7		24-38		Traces.....	40-65	26	Northern and middle interior.
	26	Manitoba....	30.2		New York....		29.5		46-52		Light.....	50-60	27	Portions of northern interior.
June....	12	N. Dakota....	30.4		Kansas.....		29.9		30-52		Local.....	50-65	13	Northern interior.
Sept....	24	Manitoba....	30.3		E. Canada....		29.9		32-52		None.....	50-80	25	Northern and portions of middle interior.
	11	Wyoming....	30.5		Lake Erie....		29.7		29-30		Traces.....	32-40	12	General over interior.
Oct....	19	N. Dakota....	30.3		New Eng....		29.7		28-42		None.....	35-50	20	Much of interior.
May....	27	W. Canada....	30.2		Illinois.....		29.6		30-36		Light.....	35-45	28	
	29	Dakotas....	30.4		Missouri....		29.7		30-44		Heavy E....	50-60	30	Northern and middle interior.
Sept....	9	E. Mont....	30.5		E. Canada....		29.55		24-30		Traces.....	30-40	10	General except Lake Michigan shore.
	20	N. Minn....	30.4		New England..		29.8		20-40		None.....	38-60	21	
1907 May....	26	Montana....	30.3		Lake Mich....		29.6		26-38		Light.....	45-55	22	General in interior except extreme south.
	21	Iowa.....	30.2		Lake Sup'r....		29.7		30-44		None.....	30-40	26	North and middle interior.
Sept....	25	Montana....	30.3		New Eng....		29.7		34-40		None.....	40-55	5	General.
	7	Montana....	30.4		Lake Mich....		29.9		38-42		Local.....	40-55	8	
Oct....	12	Red R. Val....	30.4		Lake Erie....		29.9		18-26		Light.....	35-40	13	











consin on the following morning. In both cases, however, cool northerly to westerly winds blowing over Wisconsin kept the air temperature down during the day, and were followed at night by the clear skies and light winds which usually prevail near a high pressure center. Thus weather conditions on both occasions were very favorable for the heavy to killing frosts which actually occurred over nearly the entire state.

## DAMAGE BY FROST

The following extract from the *Cyclopedia of Agriculture* (L. H. Bailey, Editor) is of interest in this connection:

“Some plants may be frozen with impunity provided they are allowed to thaw out slowly. Others are invariably killed by freezing.

“In general the plant that contains least water is most resistant to cold . . . Frost does not injure buds in winter when they are dry; but in spring when they are full of sap it quickly kills them. The injurious action of frost is supposed to be largely due to the extraction of water from the cells by the formation of ice in the inter-cellular spaces. The air that normally occupies these spaces is thereby driven out, so that a frozen leaf, on thawing, resembles one in which the air has been driven out by boiling. It is supposed that when the leaf is thawed slowly enough, the water is taken up again by the cells; but when it thaws quickly the water escapes by evaporation before it can be reabsorbed.”

## CROPS DAMAGED IN WISCONSIN

So far as the general crops are concerned it appears that much less damage is caused by late spring frosts than by early autumn frosts. While a killing frost in June causes some additional expense for replanting, good crops may still often be secured. A similar frost occurring early in September, however, may injure beyond recovery a maturing crop upon which much labor has been expended. Nearly all crops are more or less subject to damage. From reports of the Wisconsin State Board of Agriculture, and from the *Weather Bureau, Wisconsin Section, Climate and Crop Reports*, the following notes as to the chief Wisconsin crops injured by frost have been obtained.

*Corn.* A killing frost, which occurred about June 1. 1897, necessitated quite general replanting of this crop. As a rule, however, the damage to corn is caused by September frosts,

before the kernel has hardened, and may amount to from 10 to 30 per cent. of the value of the crop which is then of low grade for selling but still suitable for home consumption.

*Small grains.* These are liable to little injury, except occasionally in June, as they are harvested before the autumn frosts.

*Fruits.* Chiefly damaged by the freezing of buds or blossoms late in the spring, the crop for that season being thus lessened or destroyed.

*Cranberries.* Grown on bogs which are particularly liable to summer frosts. When not protected, as much as one-half of the crop has been destroyed in August. Frosts in June may also injure the blossoms.

*Potatoes.* June frosts often cut down the young vines which often start again without replanting. Matured potatoes are sometimes left in the ground until late in the fall, when damage may be caused by actual freezing of both earth and tubers.

*Garden crops.* These may be injured by both late June and early September frosts.

*Tobacco.* The seed beds frequently need protecting in the spring, and resetting of fields is also sometimes necessitated by frosts. The crop is generally harvested before the occurrence of autumn frosts.

## ARTIFICIAL PROTECTION

The idea to be kept in mind is the preventing of the temperature of the plant from dropping to the freezing point. This result may be attained in several ways, such as warming the air, mixing cold with warm air, raising the dew point, retarding radiation, and covering the plants.

Dry heat for increasing the air temperature has been experimented with to some extent. The usual method is to build fires of some cheap material in, or to the windward of, the area to be protected. In upper Michigan log and stump fires retarded the fall of temperature on their leeward side by 2°. The protection afforded by this method seems in general to be slight.

A fire built in a hollow or in the drainage bed of the down-flowing cold currents tends to produce an artificial circulation,

and thus to prevent the cold air from accumulating in the low places or frosty spots.

The direct introduction of moisture into the air from sprinklers which throw a fine spray at some elevation has been found to work well in some places. Sprinkling plants and the flooding of irrigated plots in frosty weather have been practiced with success. All of these processes increase the moisture content of the air and thus tend to retard its decrease in temperature. As a rule they can be used successfully only when the air is not too dry, i. e., has a fairly high dew point, and has little motion.

For preventing radiation of heat, screens of glass, cloth and lath have been used. The first material is well known in this connection, on account of its use in green-houses where it allows solar radiation to enter freely but prevents the escape of the long, terrestrial, heat waves. Cloth and lath screens have been utilized in Europe and in Florida and California for protecting grapes, oranges, pineapples and other fruits.

Artificial clouds of smoke may be produced by burning tar, crude petroleum, damp straw, stable manure, etc., to the windward of the area to be protected. These clouds tend to hinder the escape of radiation at night, affording protection in that way.

Smudge fires of damp material also add some moisture to the air, thus raising the dew point. Portable smudge fires have been used with much success in California for protecting considerable areas. Tar pots were placed upon a wagon bed protected with earth. Coarse wire netting was stretched above, and on this damp stable manure or wet straw was placed and kept moist by sprinkling with water. The dense smoke from the burning tar rose through the damp material above it and became laden with moisture, and as the wagon was driven about this cloud became spread over a considerable area. Stationary fires built in the same or similar manner, at frequent intervals in orchards, also gave satisfactory results.

Protection by means of any sort of fires would, of course, be impracticable if there were much wind when the frost occurred,

but in that event the danger of frost is lessened by the wind itself.

Cranberries are quite commonly protected by flooding the marshes with water from reservoirs. (See plate IX.) In this process the warmth of the water is aidful, as especially in autumn its temperature may be much above the freezing point so that a low air temperature ( $25^{\circ}$  or lower) is required to freeze it. Much advanced work has been done in Wisconsin with this crop, and for further information the reader is referred to the excellent publications of the Wisconsin Agricultural Experiment Station.

Many low garden crops may be protected by light coverings of some light material. Strawberries are covered with the hay or straw, which is often placed as a mulch between the rows. A light covering of earth may be plowed over young potato plants which should not be left covered thus too long. Many plants may be protected by a covering of paper or light cloth.

Protecting devices should be used only on the eve of the occurrence of frost, as the use of heat or water tends to produce abnormal growth, thus making the plants tender and more liable to damage.

In general artificial protection may be profitably attempted only with the more concentrated crops, such as garden stuff, small fruits and those plants whose money return per acre warrants some expense for protection.

## POSSIBILITIES OF PROTECTION IN WISCONSIN

With the exception of the flooding of cranberry bogs mentioned above, little attempt has been made to protect growing crops in this state. The following suggestions may, however, be of value for future work and experiment.

*Avoiding frost.* In a state so far north as this, where frosts may occur in some counties in nearly every month of the year, every natural advantage for avoiding them should be seized upon. The influences of the great lakes and of smaller bodies of water, of slope, elevation, drainage and surface covering need to be carefully observed. Undoubtedly there are large areas

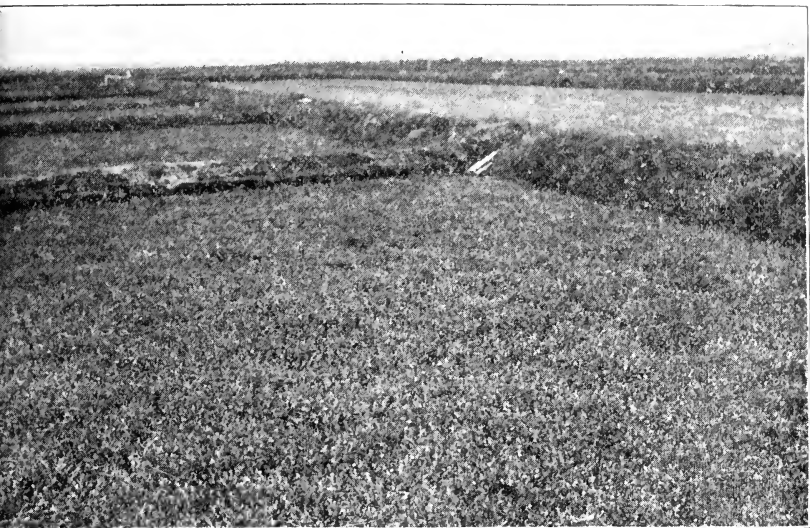


PLATE VIII.—A TYPICAL CRANBERRY MARSH IN CENTRAL WISCONSIN.  
(Courtesy of Wisconsin Agricultural Experiment Station.)



PLATE IX.—CRANBERRY MARSH IN CENTRAL WISCONSIN FLOODED TO  
PREVENT INJURY BY FROST. (Courtesy of Wisconsin Agricultural  
Experiment Station.)

along the shores of Lakes Michigan and Superior, and smaller areas scattered throughout the state, which are nearly immune to frost during the crop growing season. A knowledge of the limits of these areas is especially desirable in view of the difficulty of protecting artificially the large general crops. Attention should also be given to the selection of early ripening varieties of plants, thus avoiding autumn frosts. In localities which are peculiarly liable to frost only the more hardy crops should be cultivated. Thus much damage may be avoided.

*Crops covering large areas.* Unquestionably the most economical method, which is also effective, for protecting such crops as corn, the small grains, potatoes, tobacco, orchard fruits, etc., is by covering the fields with artificial clouds of smoke from smudge fires. Either the portable smudge previously described may be used, or a number of small fires (15 to 30 per acre) may be built. The material to be burned may vary considerably, depending upon its availability and cost, but should be one which will burn slowly, producing much smoke. The following are considered good producers of smudges: mixtures of tar, oil and refuse from refineries with wood chips, damp straw, leaves, peat, corn stalks and the fine refuse from soft coal; stable manure, saw dust, grass, prunings from trees; a mixture of gas tar and saw dust is especially recommended. Dry materials should be moistened, causing them to burn more slowly, produce more smoke, and also add moisture to the air.

Preparation for these fires should be made in advance so that there may be no delay in starting them. When the temperature falls to  $40^{\circ}$  in the early evening, with clear sky and little wind and no prospect of much wind or clouds before morning, the fires should be started by 9 P. M. and kept burning until danger from frost is past. If the material used is one which produces much heat, as well as smoke, it might be possible to wait for a temperature of  $35^{\circ}$  at midnight before lighting the fires. There are devices for automatically warning when the air reaches a certain dangerous temperature.

The best results with smudges are obtained on level lands, where the smoke will not drain away.

Where water in large quantities is available, it may be worth



while to plan some irrigation system for flooding the fields on the day before frost is expected. Very complete protection has been obtained by this method in California, the water evaporating and filling the air with moisture so that the fall in temperature of the latter was retarded. The soil should be thoroughly moistened and kept wet until frost danger is past.

The proper cultivation of the soil, when frost threatens, to cause greater evaporation from the surface of the ground into the air is considered to have a protective influence, and could be easily applied to large areas.

*Small fruits and garden crops.* These may be more satisfactorily protected on account of the smaller areas which they cover. For these also the smudge fire and irrigation methods are to be recommended, especially if the crops are grown on a commercial scale. Small home gardens may be even more simply guarded, as the following extract from the *Monthly Weather Review* (Abbe) for August, 1895, indicates:

“Covering with some sort of shield protects the plants from radiation and saves them from freezing, even though the surface of the ground may get very cold. Such covers may be made of tubs or half barrels; of conical caps of pasteboard, matting or newspaper; of light wooden frames over which cambric or mosquito bar is stretched; of coarse matting or of rough trellis work. Sometimes a bolt of cloth is rolled up on a reel at one end of a row of plants, and two persons holding the end of the cloth walk down the row unrolling the cloth and covering the plants completely; short stakes should be placed along the row so that the screen will rest upon them a few inches above the plants. For a single night old newspapers are as useful as cloth. A gentleman in Washington has made a very serviceable screen of ordinary laths tied together about two inches apart on a pair of ordinary clothesline ropes. Flexible wire will do as well. This screens against hot sun by day and frost by night, and can easily be rolled up out of the way when not in use. Old Venetian blinds, Japanese screens, or old floor matting are fair substitutes. Rows of vertical walls or screens tipped against each other, forming an A, do good service.

“Rows of tall-growing plants set between the rows of delicate vegetation act as shields against wind and radiation. Thus tall hop vines on poles, tall corn or cane stalks, or pole beans protect the lower vegetation from cooling by radiation. When the plants are very small a mulching of straw may be spread over them for the night.”

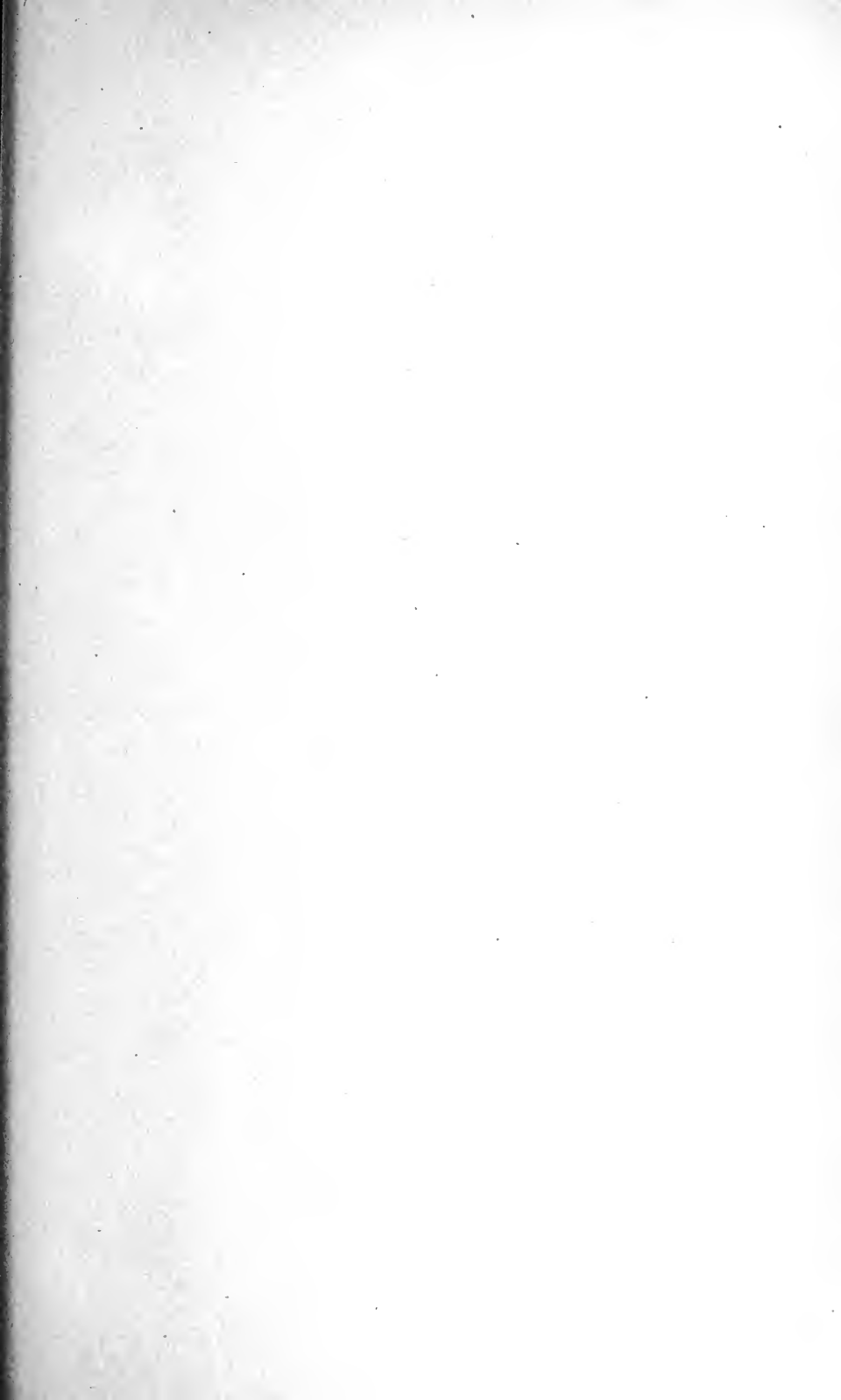
One of the simplest methods of warding off frost injury is by the free use of water. Thoroughly sprinkling flower gardens, fruit patches, grape vines and similar vegetation on the eve of frost affords excellent protection, frequently more effective than the use of solid coverings. By means of hose or sprinkling carts large areas could be thus protected. The spraying of frozen vegetation is also claimed to diminish the damage caused.

The foregoing protective methods are practically all based upon the fact that frosts during the crop growing season almost always occur during temperature inversions, that is, with freezing temperature at the ground but with warmer air above. When weather conditions are favorable for the whole mass of the air to reach a freezing temperature only some cover which is fairly tight and impervious to cold, such as water in the case of the cranberry bogs, can be depended upon to prevent damage to vegetation.

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